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Low-Cost, Community-Based Air Quality Monitoring Networks for Nigerian Cities: A Review

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Abstract

In Nigerian cities, air pollution is a major environmental health risk as the concentration of fine particulate matter (PM2.5) is regularly exceeded in Lagos, Port Harcourt, Ibadan and the Niger Delta by several folds, despite the absence of monitoring infrastructure in most cities to which the regulatory standards are met. To address this data gap, low-cost sensor (LCS) technology and community-based and citizen-science deployment models are appearing promising as a viable way to meet the needs. This review collates the evidence between 2020 and 2025 on design, deployment, calibration and governance of low-cost, community-based air quality monitoring networks in the Nigerian context and experience in similar sub-Saharan African contexts, such as citizen-science programmes in Kenya and Air Sensor Evaluation and Training Facility in Ghana, and AirQo network in Uganda. The principles of the sensors used and known biases are discussed, especially humidity and dust- related biases during the Harmattan season; a summary of documented LCS deployments in the cities of Nigeria is provided; and community engagement models are examined that connect sensor data collection with public awareness and policy advocacy. Major problems remain are the lack of co-located reference instruments for calibration, poor electricity and internet connections, weak technical capacity and funding, and poor linkage between national air quality regulation. We suggest a model that integrates a hybrid reference–low-cost network, a machine-learning based calibration tailored to the tropical environment, continuous community ownership, and closer links with the National Environmental Standards and Regulations Enforcement Agency (NESREA) regulatory framework. The challenge of scaling up such networks could significantly contribute to the evidence base for air quality management and public health protection in Nigeria's rapidly urbanising cities.

Keywords: *air quality monitoring, low-cost sensors, citizen science, particulate matter, Nigeria, sub-Saharan Africa.*

1. Introduction

Ambient air pollution is one of the highest environmental threats to health globally and is disproportionately affecting low- and middle-income countries (LMICs) where urbanisation, the use of biomass energy, vehicle emissions and industrial pollution are often exceeding the development of environmental regulatory and monitoring

systems [1,2]. Nigeria, the most populous country in Africa, is a good example of this imbalance. Nigeria has been identified to be among the countries with the highest number of premature deaths due to air pollution, and the burgeoning of lower respiratory infection due to air pollution' changed from the fourth leading cause of premature death in 2007 to the first cause in 2017 [3]. However, reference-grade regulatory air quality monitoring stations are sparse and are not evenly distributed in Nigeria cities, which means that the government, health professionals and the public lack empirical evidence to inform their decision making on reducing exposure to air pollutants [3,4].

The pollutants that cause air pollution in urban areas are heterogeneous and vary from one city to another in Nigeria. For the fast motorisation cities such as Lagos, the main sources are vehicular emissions, heavy traffic and fossil-fuel generators used during frequent power outages [4]. Particulate matter, oxides of nitride and other pollutants from gas flaring during oil and gas production have been associated with increased health risk (mainly respiratory and dermal) in the surrounding communities of the Niger Delta [5–8]. In northern and central Nigeria, the Harmattan is a dry season that can transport large amounts of mineral dust from the Sahara into Nigeria, significantly increasing PM2.5 and PM10 levels from November to March [9]. In addition to these emissions sources, open waste burning, substandard road surfaces, and household solid fuel combustion are further sources of pollutants characteristic of Sub-Saharan African cities [2].

Costs for reference-grade instrumentation, in the tens to hundreds of thousands of dollars per station, have led to the widespread adoption of low-cost sensor (LCS) technology as a complementary or temporary monitoring solution in Africa [9,10]. These light-scattering optical units, which are usually in the range of $100 to 2,500, are able to estimate particulate mass concentration based on light scattering and can be placed at a much higher spatial density than reference instruments [11]. If deployed using a community-based or citizen-science approach (meaning that citizens, schools, or civil-society organisations deploy, keep, and interpret the data collected by the sensors), LCS networks can also create local awareness, produce hyperlocal evidence for advocacy, and establish informal accountability pressures for polluters and regulators [1,12].

This review collates published peer-reviewed literature from the period 2020 to 2025 surrounding the topic of low-cost, community-based air quality monitoring in Nigeria, such that the Nigerian experience is placed in the context of the wider Sub-Saharan African experience, where Nigerian studies are limited. For each question, we first draw on the available evidence to answer it: (ii) How is the implementation and effectiveness of LCS in Nigeria and similar contexts? (iii) What models of communities and citizens' science have been successful in sustaining these networks? and (iv) What are the challenges and opportunities to scaling up these networks into Nigeria's environmental governance systems?

2. Methodology

2.1 Review Design

This study used narrative literature review method to explore the possibility of the use of low cost, community-based air quality monitoring network to mitigate urban air pollution in Nigerian cities. A literature review was conducted to collate existing research on low-cost air quality sensors, community involvement in environmental monitoring, sensor calibration and validation, data quality, and policy effects of decentralised air quality monitoring. Opportunities, limitations and practical approaches to implementing community-based monitoring networks in Nigeria were identified by considering relevant evidence from Nigeria as well as from other sub-Saharan African countries and international settings.

2.2 Literature Search Strategy

Literature relevant for the present study was retrieved from available academic databases and scholarly search platforms such as Google Scholar, PubMed, Scopus, and Web of Science, as available. The reference lists of relevant publications were consulted and reports from environmental and public health organisations were also used to identify additional sources. The search was mainly conducted on publications from January 2020 to December 2025, and publications from before that date were included if they supplied valuable background data on the use of low-cost sensor technologies, calibration methods, or air quality monitoring.

The search terms and combinations used were: low-cost air quality sensors, community-based air quality monitoring, citizen science, particulate matter, PM2.5, urban air pollution, sensor calibration, Nigeria, and sub-Saharan Africa. The terminology used in the searches was modified to suit the needs of each database and the content of the literature being considered.

2.3 Literature Selection and Relevance

Publications were deemed relevant if they dealt with one or more of the following aspects: low-cost air quality monitoring technologies; measurement and assessment of particulate matter and other urban air pollutants; sensor calibration and data validation; community participation and citizen-science approaches; air quality monitoring in Nigeria or a similar setting in Africa; and governance,

financing and policy needs for expanding air quality monitoring networks.

Research, review, technical publications and credible institutional reports were considered relevant. The selection of the literature was guided by its relevance in addressing the literature review objectives, methods or arguments presented were clear, and the literature helped to understand the technical, social, or policy aspects of the community-based monitoring. The following process did not follow a formal systematic-review protocol, but rather the review questions themselves guided the process:

2.4 Data Extraction and Thematic Synthesis

Information from the selected literature was organised around the main objectives of the review. The main components covered: study location, monitoring technology, pollutants monitored, calibration and validation, principal findings, community engagement models, implementation challenges and policy implications. Special focus was placed on the use of evidence from selected Nigerian cities (Lagos, Port Harcourt and Ibadan) where existing literature was accessible. Comparative insights were drawn from studies conducted in other African countries and in international settings, bearing in mind the different infrastructure, climate, institutional capacity and regulatory environments.

The findings were integrated by using a narrative thematic synthesis approach. The evidence was grouped into five themes: (i) urban air pollution and gaps in monitoring in Nigerian cities; (ii) low-cost sensor technologies and their suitability to local environmental conditions; (iii) calibration and validation, as well as data quality assurance; (iv) community participation, implementation barriers and data accessibility; and (v) integrating with policy, sustainable financing and opportunities for scaling up monitoring networks. The synthesis led to the identification of some commonalities, best and unknown practices, and implications for the formulation of locally-appropriate monitoring strategies.

2.5 Development of the Proposed Monitoring Framework

Based on the literature reviewed, a conceptual framework was developed to demonstrate the integration of the above elements in to a coordinated air quality monitoring system for Nigerian cities that utilizes low-cost sensors, reference monitoring stations, community engagement, data management, and environmental governance. The proposed framework highlights community involvement, collaboration between researchers, public institutions and relevant environmental regulatory authorities, and open sharing of data, with a focus on local sensor evaluation and calibration. It is not an empirical test-driven framework from the studies reviewed, but rather a synthesis of recommendations that were found within the literature.

2.6 The limitations of the Review are as follows:

This is a narrative review and the objective was not to be exhaustive to find all publications on low-cost air quality monitoring and to perform pooled quantitative estimation. Variations in technologies used for sensors, calibration procedures, monitoring time, and study setting may introduce evidence variation. Furthermore, in some Nigerian cities, there might be a limited number of published city-level, sustained, community-based monitoring networks. Therefore, the results of other geographical contexts were interpreted in context and the recommendations for Nigeria are considered as recommendations for further study, field validation and policy evaluation.

3. The Air Quality Burden in Nigerian Cities

The localised measurement campaigns conducted across the Nigerian cities consistently show PM2.5 levels exceeding the World Health Organisation (WHO) Air Quality Guideline (AQG) of 5 µg/m³ (annual average) and 15 µg/m³ (24-hour average); and are often exceeding Nigeria's National Ambient Air Quality Standard (NAAQS) of 40 µg/m³ (24-hour average) stipulated by NESREA [9,10]. The seven-month low-cost sensor campaign in Ibadan also showed peak outdoor PM2.5 concentration during the Harmattan season at 109.3 µg/m³, whereas the rainy season concentration was 24.5 µg/m³, and indoor-outdoor correlation (indoor–outdoor $R^2 > 0.9$) indicated high PM2.5 infiltration into the indoor environment [10]. The meteorological modulation of PM concentration was also observed in a semi-urban low-cost sensor network in Ile-Ife which confirmed the need for continuous and high temporal-resolution monitoring rather than short spot-check campaigns [13]. However, in a multi-city pilot which included Nnewi, Awka, and Enugu in Nigeria, Nigerian sites had some of the longest durations with an exposure to PM2.5 levels above 250 µg/m³ across all cities studied, in addition to Kampala, Uganda [1].

In Niger Delta, gas flaring is a unique and severe sources of pollution. Significantly higher levels of NO2 and PM10 than the allowable levels set by WHO were detected around the gas flaring stations and higher numbers of reported respiratory and dermal symptoms were observed in communities around the gas flaring stations when analysed by spatial analysis [5]. Complementary narrative and spatial reviews support that the cost to the ecosystem and community health of gas flaring in the Niger Delta are measurable and the enforcement of the flare-reduction goals is weak [6–8]. In total, this data shows the intensity and spatial variation of the air pollution situation in Nigeria,

and supports the need for more frequent and widespread low-cost monitoring, not just a few centralised reference stations.

4. Low-Cost Sensor Technology: Principles, Platforms and Performance

4.1 Measurement Principles

The majority of low-cost particulate sensors used in Africa are based on optical particle counter (OPC) technology, such as units measuring particle number and inferring mass concentration by assuming an optimal particle density and size distribution for the particles (e.g., Plantower PMS-series, Sensirion, Alphasense). The assumption is a significant measurement uncertainty as it does not consider regional variations in aerosol composition, hygroscopic growth under relative humidification and mineral dust characteristics of Harmattan season [11,14–16]. There are some gas-phase low-cost sensors (electrochemical or metal-oxide types) for NO2, CO and O3, but they are typically less developed and less commonly used in African settings than particulate sensors [2].

4.2 Calibration in Tropical, Dusty Environments

One point in the literature analysed that emerged consistently was that raw low-cost sensor data must be calibrated in the field using reference-grade sensors to be able to inform policy decisions [14,17]. The most important confounder is humidity: Purple Air and similar optical sensors significantly overestimate PM2.5 at high relative humidity levels because of hygroscopic growth in the optical chamber, and humidity-correction models that are adapted to temperate climate regions do not perform well in Sub-Saharan Africa [15,16]. In coastal West Africa, intersensor variability was found to be significantly larger than intrasensor variability when eight PM2.5 low-cost sensors compared favorably against a Teledyne T640 federal-equivalent-method instrument, with an increased tendency for larger errors in the dry season when long-range dust transport comprised a significant portion of the aerosol mix [18]. Likewise, a study in Accra, Ghana conducted by collocating QuantAQ, PurpleAir, and Clarity monitors with reference instrumentation required locally developed correction factors, which were not directly obtained from studies in North America or Europe [19]. Spatial calibration methods, which are based on multiple collocated sites, can significantly reduce the bias compared with single point calibration methods [17] and machine learning calibration methods such as random forest or gradient boosting using temperature, humidity and reference concentration can improve the accuracy by a significant level when compared to the raw sensor output or simple linear correction [20]. The results have implications for Nigeria: If there is not at least a limited number of co-located reference instruments for each climatic zone, the quality of the LCS data cannot be guaranteed for health impact and regulatory uses.

4.3 Regional Sensor Platforms and Precedents

A well documented low-cost sensing infrastructure in Sub-Saharan Africa is Uganda's AirQo network, built specifically for use in resource constrained, tropical urban settings, and deployed in over 120 static and mobile nodes across several African nations, including Nigeria [21–24]. The AirQo sensor kit combines a 3D-printed weatherproof housing, solar and grid power, and a cloud-based calibration and analytics platform, specifically engineered to resist dust, heat and unreliable power [23]. For AirQo sensors, the machine-learning calibration models, compared to the Beta Attenuation Monitors, obtained significantly better accuracy of PM2.5 and PM10 measurements than the sensor output itself [20]. A co-created open dataset of hyperlocal, calibrated air quality measurements from 68 monitoring stations throughout Uganda demonstrates the importance of sharing raw and calibrated low-cost air quality data for secondary analysis and policy applications [24]. An additional benefit of using AirQo-derived data in land-use regression models is that the dense and inexpensive network can be used to enable spatially resolved exposure modelling which would be prohibitively expensive using only reference-grade instruments.

5. Models of Community Based and Citizen Science monitoring

CB-AQM is an extension of the technical LCS model by placing sensors in community buildings (houses, schools, faith institutions, neighbourhood groups, etc.) and engaging community members directly in the process of collecting, interpreting and promoting the collected data [12]. In Kibera, an informal settlement in Nairobi, Kenya, citizen-recruited hosts and low-cost sensors were employed to monitor the construction related dust and traffic pollution levels of a new road corridor; citizen engagement workshops led to better understanding of exposure risks and an increased capacity to engage the municipal authority with their own evidence [12].

This model is representative of a principle that extends to the city of Nigeria: community-based monitoring works best as a process, rather than just a data collection; it fosters local ownership and maintenance of the sensors; and creates locally relevant advocacy stories from raw data.

At local level and on an institutional basis, the deployment of low-cost interventions is still relatively small but growing in Nigeria. In an effort to develop and implement an Arduino based low-cost monitor for Port Harcourt, the authors from the initiative for 2023-2025 explicitly

identified that operation of the technical device was not as constraining as the low awareness of the community about air quality issues, sourcing challenges, lack of trained staff, and lack of funding; these constraints were therefore organisational and institutional and not just technical [9]. A multi-phase residential study in Ibadan was developed that adopted Atmotube PRO and PurpleAir sensors installed directly in households, as an example of a household-level citizen-hosted design that can be expanded to a community network, provided there are appropriate incentives and maintenance programs in place [10]. In the multinational arena, the University of Lagos led Air Quality Monitoring Research Group has recently commenced to roll out low-cost sensors integrated with AI tools, funded through an external donor, in Lagos and Port Harcourt, specifically to provide policy-relevant, real-time data, where there was none before. These are higher numbers of initiatives that show a greater institutional appetite for community anchored monitoring in Nigeria, although systematic, peer-reviewed evaluation of these Nigerian community models is still limited compared to the other countries (Uganda, Ghana, and Kenya).

6. Documented Low-Cost Sensor Deployments Relevant to Nigerian Cities

The following table (Table 1) summarises literature reviewed above from key low-cost sensor studies carried out in Nigerian cities, as well as in similar comparable Sub-Saharan contexts that are relevant to the design of networks in Nigeria. Figure 1 shows the Map of Nigeria showing the approximate locations of documented low-cost, community-based air quality monitoring deployments.

City/Location	Sensor platform	Pollutants	Key finding	Ref.
Port Harcourt, Nigeria	Arduino-based custom LCS (PM, temperature, humidity)	PM2.5, PM10	Mean PM2.5 ≈45 µg/m³ indoors (unvalidated); device design feasible but institutional constraints (funding, awareness, trained staff) limited scale-up	9
Ibadan, Nigeria	Atmotube PRO; PurpleAir	PM1, PM2.5, PM10	Median outdoor PM2.5 rose from 24.5 µg/m³ (rainy season) to 109.3 µg/m³ (Harmattan); indoor–outdoor $R^2 > 0.9$	10
Ile-Ife, Nigeria	Low-cost optical PM network	PM2.5, PM10	Airborne PM strongly modulated by prevailing meteorological conditions across a semi-urban network	13
Nnewi, Awka, Enugu, Nigeria (part of 7-country pilot)	PurpleAir-II-SD	PM2.5	Nigerian sites among the longest-duration exceedances of 250 µg/m³ across 8 sub-Saharan African countries	1
Accra, Ghana	QuantAQ Modulair-PM; PurpleAir PA-II; Clarity Node-S	PM2.5	Locally derived correction factors required; sensor bias varies with season and site	19
West Africa (coastal), regional facility	8 commercial LCS brands vs Teledyne T640	PM2.5	Low intra-sensor, high inter-sensor variability; dry-season errors up to 5× wet-season errors	18
Kampala & national network, Uganda	AirQo custom sensor kit	PM2.5, PM10	ML-calibrated network sustained across 120+ nodes; dataset of 68 stations published openly	20,21,23,24
Kibera, Nairobi, Kenya	Community-hosted LCS	PM2.5, PM10	Citizen-science deployment linked road-construction dust to elevated resident exposure; strengthened community advocacy capacity	12

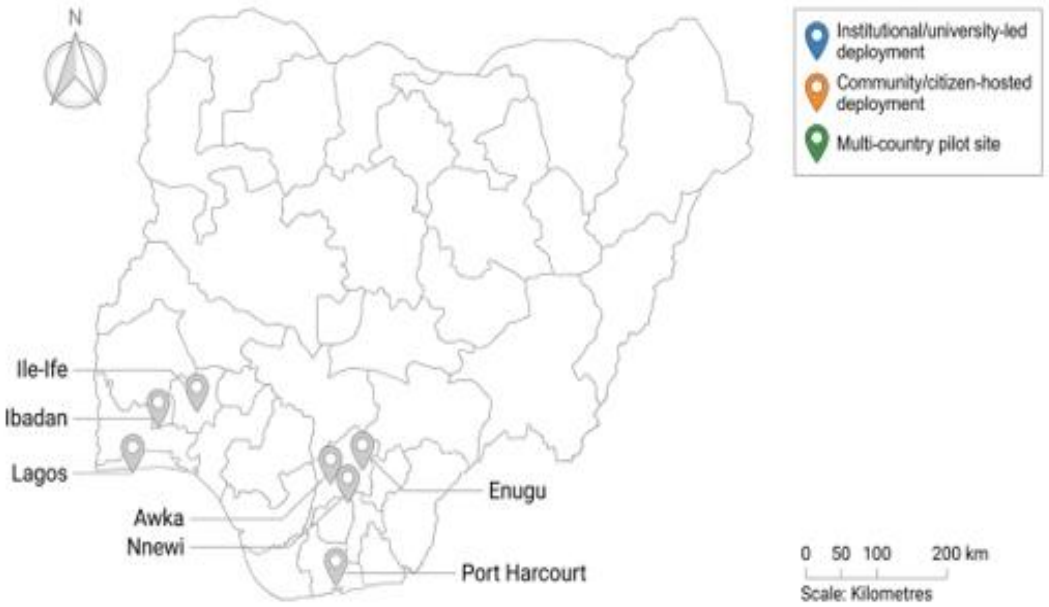


Figure 1. Map of Nigeria showing the approximate locations of documented low-cost, community-based air quality monitoring deployments discussed in this review (Lagos, Port Harcourt, Ibadan, Ile-Ife, Awka, Enugu, Nnewi)

Sources: Based on references [1,9,10,13].

7. Comparing Low-Cost Sensor Platforms for Nigerian Deployment

To choose the most appropriate sensor platform for a Nigerian network one needs to consider the cost, ability to withstand heat, dust and humidity, connectivity requirements and locally validated calibration models. Table 2 compares platforms that have been documented to be used or that are relevant for the conditions in West Africa.

Platform	Core technology	Approx. unit cost (US$)	Connectivity	Africa-specific validation	Ref.
AirQo sensor kit	Dual PM optical sensors, 3D-printed enclosure, solar/grid power	150–250	GSM/cellular, cloud dashboard	Extensively validated in Uganda, Kenya, Nigeria, Senegal, Cameroon	21,23
PurpleAir PA-II / PA-II-SD	Dual Plantower PMS5003 optical sensors	250–300	Wi-Fi + local SD card backup	Validated in Ghana, Nigeria (Ibadan), 7-country SSA pilot	1,10,15,19
Atmotube PRO	Sensirion optical PM sensor + BME280 T/RH	150–200	Bluetooth to smartphone app	Used in Ibadan household study; cross-validated against reference monitor	10
Custom Arduino/ESP32 builds	Low-cost PM/gas modules, open-source firmware	<100	GSM/Wi-Fi, variable	Piloted in Port Harcourt; limited by component sourcing and technical capacity	9
QuantAQ Modulair-PM / Clarity Node-S	Optical + gas-phase modules, cloud analytics	500–2,500	Cellular/Wi-Fi	Collocated with reference monitors in Accra, Ghana	19

8. Challenges to Sustained Community-Based Monitoring in Nigeria

The reviewed literature shows four interlinked categories of challenge that recur. First, technical calibration limitations: raw low-cost data cannot be used with confidence to measure regulatory compliance or quantitatively for health impact assessment without co-located reference-grade instruments; the default calibration models used in temperate climates do not perform well in humid coastal and dusty Harmattan-affected regions in Nigeria [14–18]. Secondly, infrastructural limitations, particularly reliability of the power supply and internet connectivity were specifically identified as operational constraints in both the Port Harcourt study and the multi-country study conducted in Sub-Saharan Africa, where design decisions need to be based on things like the local storage of data on SD cards, charging systems for batteries using solar-powered energy or GSM connectivity rather than Wi-Fi [1,9]. Third, institutional and financial constraints: the Port Harcourt case study made it clear that the poor results were not due to the sensor technology itself, but rather due to lack of awareness, training of personnel, insufficient local partnerships, and lack of funding [9] that can be broadly applied to community-based models elsewhere in the region. Fourth, constraints on governance and policy-integration: Nigeria's National Environmental Regulations (Air Quality Control) (NESREA), which sets ambient air quality standards, do not yet explicitly call on low-cost or citizen-generated data to support compliance monitoring, and thus community networks do not have a strong influence on compliance monitoring directly even in cases where they provide credible evidence [10].

9. A Framework for Scaling Community-Based Networks in Nigerian Cities

Based on the evidence that has been reviewed, we suggest a hybrid approach with a few reference-grade stations, located at NESREA or universities, as anchor points in each of the major climatic/urban zone, with community-sited low-cost stations calibrated and maintained around them. The key challenges identified in Section 8 are summarised in Table 3, with strategies to mitigate the challenges identified from the evidence reviewed. Figure 2. Schematic architecture of a hybrid, community-based low-cost air quality monitoring node for Nigerian urban deployment, showing sensing, power, connectivity, and calibration data flow.

Challenge domain	Specific issue	Recommended mitigation	Supporting evidence
Technical/calibration	Humidity and Harmattan dust bias raw PM readings	Deploy locally derived, season-specific correction models (e.g., random forest, spatial regression) trained on Nigerian reference co-location data	14–17,20
Infrastructure	Unreliable grid power and internet	Use solar charging, local SD-card logging with periodic manual retrieval, and low-bandwidth GSM telemetry	1,9,10
Institutional capacity	Limited trained personnel and local partnerships	Establish university–community partnerships with structured technician training and maintenance schedules	9,12
Funding sustainability	Reliance on short-term donor or research grants	Diversify funding via state environmental agencies, private-sector CSR, and cost-shared academic consortia	9
Governance integration	No formal role for LCS/citizen data in regulatory compliance	Develop a NESREA data-quality accreditation pathway for calibrated community networks to feed advisory (not sole compliance) air quality indices	10
Community ownership	Risk of disengagement after initial novelty	Embed sensors in existing community structures (schools, associations) and provide regular, accessible data feedback to hosts	12

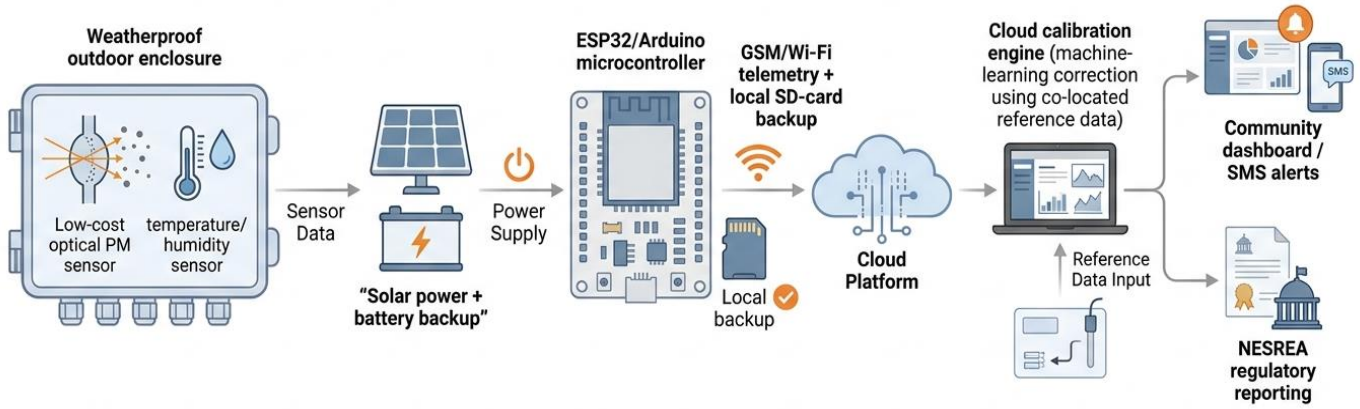


Figure 2. Schematic architecture of a hybrid, community-based low-cost air quality monitoring node for Nigerian urban deployment, showing sensing, power, connectivity, and calibration data flow.

Sources: Adapted from references [9,14,20,21,23].

10. Recommendations for Research and Practice

The synthesised evidence reveals five priorities that support progress towards the advancement of low-cost community-based air quality monitoring in Nigerian cities. 1) Invest in a minimal number of reference-grade co-location sites (at least one per main climatic zone) to provide locally valid, season-specific sensor calibration [14–18]. Secondly, to normalize the approach to open data sharing after the AirQo hyperlocal dataset, so that researchers, regulators, and citizens can access community-generated data, both raw and calibrated. Third, acknowledge a role for community and low-cost network data within the air quality reporting and public advisory roles of NESREA, even if not at regulatory compliance level [10]. Fourth, plan the design of the network infrastructure and connectivity in Nigeria taking into account the country's infrastructural limitations including intermittent power and internet connectivity, based on the lessons learnt from the AirQo solar/GSM design, and the documented failures in the Port Harcourt pilot [9,21,23]. Fifth, do not distribute the sensors as 'one-off' projects, but rather train local residents through participatory initiatives that also include data collection, that develop their capacity to interpret the data and advocate for action, as with the Kibera approach [12]. Figure 3. Conceptual framework linking community engagement, calibrated low-cost sensing, and policy feedback in a Nigerian air quality monitoring network.

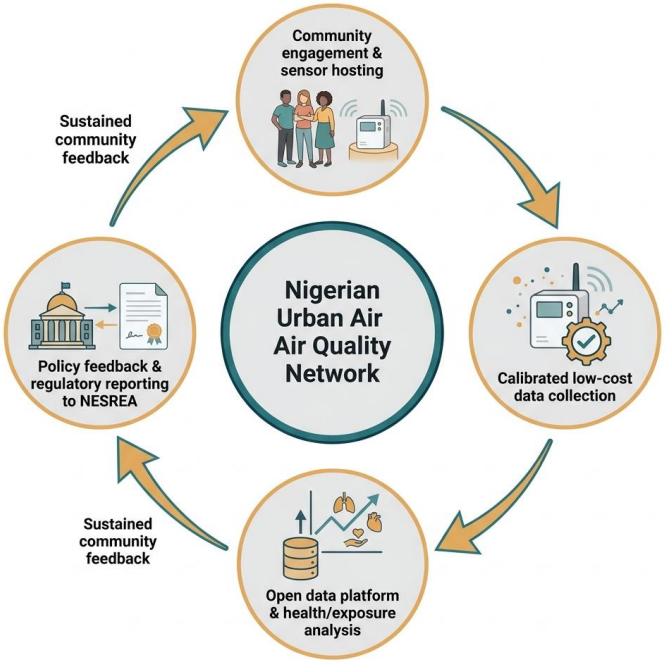


Figure 3. Conceptual framework linking community engagement, calibrated low-cost sensing, and policy feedback in a Nigerian air quality monitoring network

Sources: Adapted from references [9,10,12,20,24].

11. Conclusion

The air pollution burden in Nigerian cities is significant and unevenly distributed, largely due to the emissions from vehicles, use of fossil fuel powered generators, gas flaring and dust from the Harmattan season, but is not sufficiently met by traditional reference-grade monitoring systems. Scientifically sound and affordable way to close this evidence gap is low-cost sensor technology when used with careful calibration for local humidity levels and dust levels, and with a sound community-based deployment model. The regional initiatives reviewed here, especially projects such as AirQo in Uganda, the sensor evaluation facility in Ghana, and the citizen-science initiatives in Kenya, as well as the new pilots currently under way in Nigeria (Port Harcourt, Ibadan and Lagos), highlight that the main challenges are not necessarily technological, but institutional: funding sustainability, local staff training, power and connectivity, and formal integration in the national environmental governance system. The hybrid approach of having a modest reference-grade backbone network with dense, community-based low-cost networks, and locally developed machine-learning calibration, while improving the engagement of the NESREA, is a practical and evidence-based solution to comprehensive, policy-relevant air quality monitoring in the fast-growing cities of Nigeria.

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Conflict of Interest Statement

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Author Contributions

All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work.

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